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28. Physical Layer Link Signalling for 10 & 100 Mb/s Auto-Negotiation on Twisted-Pair

28.1 Scope

28.1.1 Overview

This document describes the NWay Auto-Negotiation algorithm that allows a device to advertise enhanced modes of operation it possesses to a device at the remote end of a link segment and detect corresponding enhanced operational modes that the other device may be advertising.

The objective of the Auto-Negotiation algorithm is for the devices at each end of a link segment to determine the modes of operation supported by the device at the other end. Auto-Negotiation is performed out of band using a modified 10BASE-T link integrity test pulse sequence, such that no packet or upper layer protocol overhead is added to the network devices. (See Fig 28-1)

The algorithm allows the devices at both ends of a link segment to request and acknowledge use of the common mode(s) of operation that both devices share, and to reject the use of operational modes that are not shared by both devices. When more than one common mode exists between the two devices, a mechanism is provided to allow the devices to resolve to a single mode of operation using a pre-determined priority resolution table. The Auto-Negotiation algorithm allows the devices to switch between the various operational modes in an ordered fashion, permits management to disable or enable the Auto-Negotiation algorithm, and allows management to select a specific mode. The Auto-Negotiation algorithm also provides a Parallel Detection capability to allow 100BASE-TX and 100BASE-T4 compatible devices to be recognized, even though they may not provide NWay Auto-Negotiation.

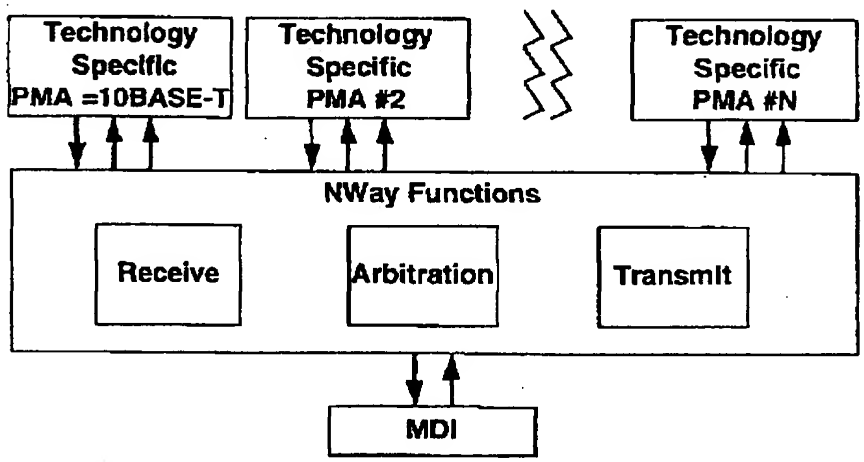


Fig 28-1. High Level Model

The basic principle to achieve Auto-Negotiation is to pass information encapsulated within a burst of closely separated link integrity test pulses that individually meet the 10BASE-T Transmitter Waveform for Link Test Pulse (Fig 14-12). This burst of pulses is referred to as a Fast Link Pulse (FLP) Burst. Each device capable of Auto-Negotiation issues FLP Bursts at power up, on command from management, or due to manual (user) interaction. The FLP Burst consists of a series of link integrity test pulses which form an alternating clock/data sequence. Extraction of the data bits from the FLP Burst yield a link code word which identifies the operational modes supported by the remote device, as well as some information used for the Auto-Negotiation algorithm's handshake.

To maintain interoperability with existing 10BASE-T devices, the algorithm also supports the transmission of 10BASE-T compliant link integrity test pulses. 10BASE-T link pulse activity is referred to as the Normal Link Pulse (NLP) sequence and is defined in 14.2.1.1. A device which fails to respond to the FLP sequence and returns only the NLP indication is treated as a 10BASE-T compatible device.

28.1.2 Definitions

Ability. A mode that a device can advertise using the FLP Burst. For modes that represent a type of data service, a device shall be able to operate that data service before it may advertise this ability. A device may support multiple abilities.

Advertised Ability. A mode that is advertised within the FLP Burst that is derived from the base Link Code Word.

Agile Device. A device that supports automatic switching between multiple physical layer technologies.

Auto-Negotiation. The algorithm which allows 2 devices at either end of a link segment to negotiate a common data service function.

Eight Pin Modular. ISO/IEC 8877

Fast Link Pulse (FLP) Burst. A group of no more than 33 10BASE-T compatible link integrity test pulses transmitted within a 2 ms (nominal) window. FLP Bursts have identical spacing as NLPs, one burst every 16±8ms. The individual link integrity test pulses within an FLP Burst are the same as specified in Fig 14-12. Each FLP Burst encodes 16 bits of data using an alternating clock and data pulse sequence.

FLP Burst Sequence. The sequence which FLP Bursts are transmitted by the Local Station. FLP Bursts are transmitted every 16±8ms during Auto-Negotiation. This term is intended to differentiate the spacing between FLP Bursts from the individual pulse spacings within an FLP Burst.

Link Code Word. The 16 bits of data encoded into a Fast Link Pulse Burst.

Link Partner. The far-end device at the opposite end of a link segment from the Local Station. The link partner device may be either a DTE or repeater.

Local Ability. A mode that a device possesses and may advertise by including this information in the FLP Burst via the Link Code Word.

Local Station. The local device which may attempt to Auto-Negotiate with a Link Partner. The Local Station may be either a DTE or repeater.

Next Page Bit. A bit in NWay's base Link Code Word encoding that indicates that there are additional Link Code Words with potentially different standard encodings to be transferred.

Normal Link Pulse (NLP). A 10BASE-T compatible link integrity test pulse as defined in Fig 14-12.

NLP Sequence. A 10BASE-T compatible link integrity test pulse sequence, as defined in 14.2.1.1, where one NLP is transmitted every 16±8ms.

NLP Receive Link Integrity Test Function. NWay's link integrity test function which allows backward compatibility with the 10BASE-T Link Integrity Test Function of Fig 14-6.

NWay. The specific Auto-Negotiation algorithm defined in this specification that allows a single "Way" for two stations with "N" different common modes of communication to establish a single link using the highest common denominator mode of operation.

Page. The encoding for a Link Code Word. NWay can support an arbitrary number of Link Code Word encodings. The base page has a constant encoding as defined in 28.2.1.1.2. Additional pages may have a standard encoding.

Parallel Detection. The ability to detect 100BASE-TX and 100BASE-T4 technology specific link signalling while also trying to detect the NLP sequence or FLP Burst sequence.

Priority Resolution Table. The look-up table used by NWay to select the network connection type where more than one common network ability exists (100BASE-TX, 100BASE-T4, 10BASE-T, etc.) The priroty resolution table defines the relative hierarchy of connection types from the highest common denominator to the lowest common denominator.

Remote Fault. The generic ability of a link partner to signal its status even in the event that the device indicating the remote fault may not have an operational receive link.

Renegotiation. Restart of the Auto-Negotiation algorithm caused by management or user interaction.

Selector Field. A 5 bit field in the base Link Code Word encoding that is used to encode up to 32 types of Link Code Words.

Technology Ability Field. An 8 bit field in the base Link Code Word encoding that is used to indicate the abilities of a Local Station, such as support for 10BASE-T, 100BASE-TX, 100BASE-T4, or Full Duplex.

28.1.3 Application Perspective/Objectives

The Auto-Negotiation algorithm is designed to be expandable and allow IEEE 802.3 compatible devices using an 8 Pin Modular connector to self configure a jointly compatible operating mode. Implementation of the Auto-Negotiation algorithm shall be optional. However, for CSMA/CD compatible devices using an 8 Pin Modular connector and which encompass multiple operational modes, it is highly recommended that this method alone be utilized to perform the negotiation of the link operation.

The Auto-Negotiation algorithm is designed to meet the following objectives:

1 Must interoperate with the IEEE 802.3 10BASE-T installed base.
2 Must allow automatic upgrade from the 10BASE-T mode to the desired "High Performance Mode".

3. Requires that the 10BASE-T data service is the Lowest Common Denominator (LCD) that can be resolved. A 10BASE-T data service is not required to be implemented, however. Only the NLP Receive Link Integrity Test Function is required.
4. Shall be reasonable and cost effective to implement.
5. Must provide a sufficiently extensible code space to:
    - Meet existing and future "improvements"
    - Allow simple extension without impact of the installed base
    - Accommodate remote fault signals
    - Accommodate link-partner ability detection.
6. Must allow manual or Network Management configuration to override the Auto-Negotiation.
7. Must be capable of operation in the absence of Network Management.
8. Must not preclude the ability to negotiate "back" to the 10BASE-T operational mode.
9. Shall operate when:
    - The link is initially electrically connected
    - A device at either end of the link is powered up or reset
10. The Auto-Negotiation algorithm may be enabled by automatic, manual, or Network Management intervention
11. Shall complete the Auto-Negotiation algorithm in a bounded time period.
12. Shall be mandatory for future CSMA/CD compatible RJ-45 LANs with any 10BASE-T data service.
13. Must not cause corruption of IEEE 802.3 MIB statistics.
14. Operate on a peer-to-peer exchange with no requirement for a master device (not master-slave).
15. Must be robust in the UTP cable noise environment.
16. Must not significantly impact EMI/RFI emissions.

28.1.4 Relationship to ISO/IEC 8802-3

The Auto-Negotiation algorithm is provided at the Physical Layer of the OSI reference model as shown in Fig 28-1. Devices which support multiple modes of operation can advertise this fact using this algorithm. The actual transfer of information of ability can only be observed at the MDI or on the medium. NWay signalling does not occur across either the AUI or MII. Control of the Auto-Negotiation algorithm is supported through the Management Interface of the MII. If an explicit embodiment of the MII is supported, the control and status registers to support the Auto-Negotiation algorithm shall be implemented in accordance with the definitions in Clause 22. If a physical embodiment of the MII is not present, then it is strongly recommended that the implementation provide control and status mechanisms equivalent to those described in Clause 22 and 28.2.1.4 for manual and/or management interaction.

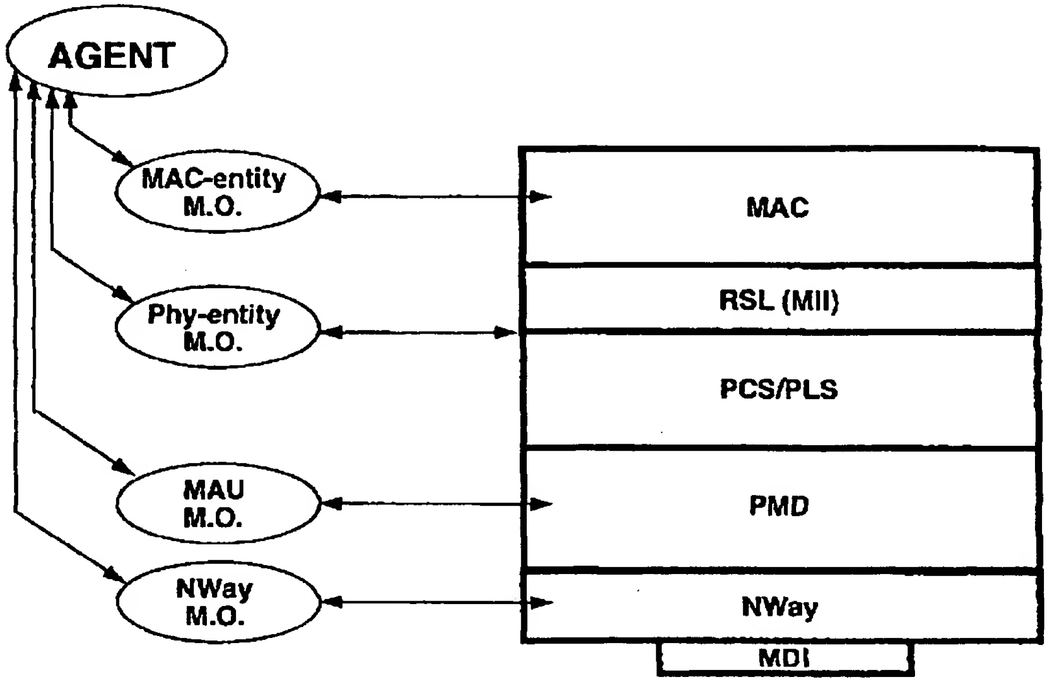


Fig 28-2 Location of Auto-Negotiation algorithm within the ISO reference model

28.1.5 Compatibility Considerations

The Auto-Negotiation algorithm is designed to be completely backwards compatible and interoperable with all pre-existing 10BASE-T compliant devices. In order to achieve this, a device supporting the Auto-Negotiation algorithm shall provide a compatible 10BASE-T link integrity test pulse function as defined in Fig 28-16.

Implementation of the Auto-Negotiation algorithm is optional. However, for CSMA/CD compatible devices using an Eight Pin Modular connector and which encompass multiple operational modes, if a signalling method is used to automatically configure the preferred mode of operation, then the Auto-Negotiation algorithm shall be used in compliance with this specification as defined in the following sections. Non CSMA/CD abilities may be advertised. If the devices use 10BASE-T compatible link signalling to achieve this mode detection, the device shall implement the Auto-Negotiation algorithm as administered by this specification.

While this Auto-Negotiation algorithm shall be implemented in multi-mode CSMA/CD compatible LANs utilizing the Eight Pin Modular connector that offer an auto-negotiation mechanism, the use of this algorithm does not mandate that the 10BASE-T packet data communication service must exist. A device that employs this algorithm shall support the 10BASE-T link integrity test function. The device may also need to support other technology dependent link test functions depending on the modes supported.

28.1.5.1 Interoperability With Existing 10BASE-T Devices

When a device is in the Auto-Negotiation process, it issues FLP Bursts separated by 16±8ms. The FLP Burst itself is a series of pulses separated by as little as 62.5±15µs. A 10BASE-T device will remain in the Link Test Pass state while receiving FLP Bursts. An Auto-Negotiation capable device shall recognize NLP from the 10BASE-T device and cease transmission of FLP Bursts. If the Auto-Negotiation capable device has a 10BASE-T data service, 10Mb/s communication shall be established. However, if the Auto-Negotiation capable device does not have a 10BASE-T data service, it shall not transmit NLP or FLP Bursts to force the 10BASE-T device into the Link Test Fail state(s) as indicated in Fig 14-6.

28.1.5.2 Interoperability With Auto-Negotiation Compatible Devices

An NWay Auto-Negotiation compatible device decodes the Link Code Word from the FLP Burst, and examines the contents for the highest common ability which both devices share. Both devices acknowledge correct receipt of each other's base Link Code Words by responding with an FLP Burst containing the Acknowledge Bit set. After a predetermined number of repeats of this acknowledge, both devices shall enable the highest common mode negotiated. The highest common mode shall be resolved using the priority resoloution table specified in Annex B. It may subsequently be the responsibility of a technology dependent link integrity test function to verify operation of the link prior to enabling the data service.

28.2 Functional Specification

The notation used in the state diagrams follows many of the conventions of section 1.2.1. Transistions shown without source states are evaluated at the end of every state and take immediate precedence over all other conditions.

28.2.1 NWay Functions

The Auto-Negotiation algorithm shall comprise three simultaneous operating functions interacting with Technology Dependent Link Integrity Test functions (See Fig 28-3). The NWay functions are: Receive, Transmit, and Arbitrate. The NWay functions interact with Technology Dependent Link Integrity Test functions which include, but are not limited to: 100BASE-TX and 100BASE-T4. The NLP Receive Link Integrity Test function shall be implemented and interfaced within the Receive function in all NWay implementations. The other Technology Dependent Link Integrity Test functions need to be implemented and interfaced only if the device is to support the given technology. For example, a 10BASE-T/100BASE-TX NWay capable device shall implement and interface to the 100BASE-TX Link Integrity Test function, but does not need to include the 100BASE-T4 Link Integrity Test function.

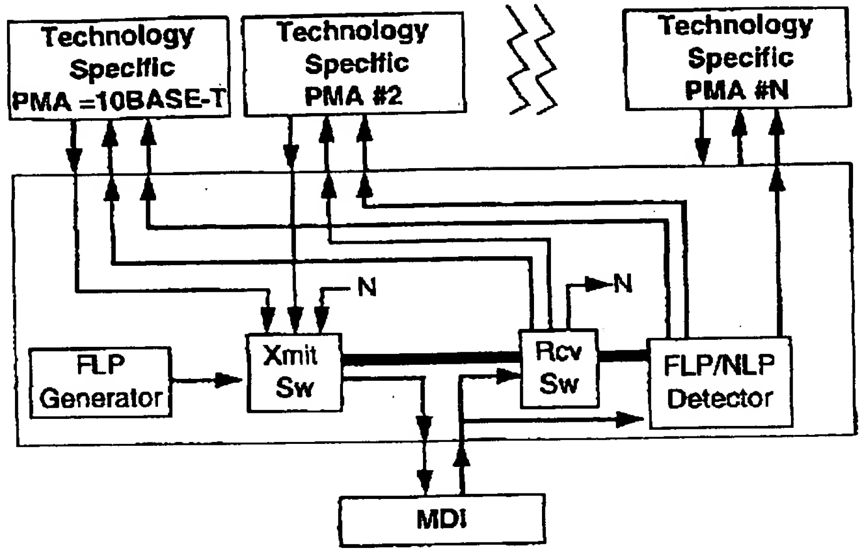


Fig 28-3 Reference Diagram

28.2.1.1 Transmit Function Requirements

The Transmit Function shall transmit FLP Bursts. The first FLP Bursts exchanged by the Local Station and its Link Partner shall contain the base Link Code Word defined in 28.2.1.4.1.1. The Local Station may modify the Link Code Word to mask out an ability it possesses, but shall not include an ability it does not possess. This makes possible the distinction between local abilities and advertised abilities so that multi-mode devices may Auto-Negotiate to modes other than the highest common denominator given in the priority resolution table.

28.2.1.1.1 Link Pulse Transmission

NWay's method of communication builds upon the link pulse mechanism employed by 10BASE-T MAUs to detect the status of the link. Compliant 10BASE-T MAUs transmit link integrity test pulses, as a mechanism to determine if the link segment is operational in the absence of packet data. The 10BASE-T NLP sequence is a pulse (Fig 14-12) transmitted every 16±8ms while the data transmitter is idle. FLP Bursts are not transmitted once data service is established. FLP Bursts shall be composed of pulses meeting the requirements of Fig 14-12 and be transmitted within 16±8ms while the transmitter is idle during Auto-Negotiation.

NWay builds upon the 10BASE-T link integrity test pulse function by substituting the FLP Burst in place of the single 10BASE-T link integrity test pulse within the NLP sequence (Fig 28-4).

Fig 28-4 FLP Burst sequence to NLP sequence Mapping

28.2.1.1.1.1 Logical 0/1 Encoding

Fast Link Pulse Bursts consist of 33 pulse positions. The 17 odd numbered pulse positions are always present and represent clock information. The 16 even numbered pulse positions represent data information; a link pulse present in an even numbered pulse position represents a logic one and a link pulse absent from an even numbered pulse position represents a logic zero. Clock pulses are differentiated from data pulses by the spacing between pulses as shown in Fig 28-6 and enumerated in Table 28-1.

The encoding of data using pulses in an FLP Burst is illustrated in Fig 28-5.

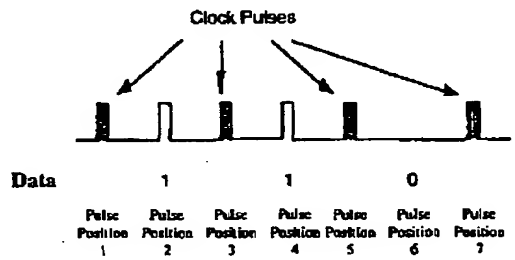


Fig 28-5 Data Bit Encoding within FLP Bursts

28.2.1.1.1.2 Transmit Timing

The first pulse in an FLP Burst shall be a clock pulse. Clock pulses shall be evenly spaced apart by 125±30µs. If the data bit representation of logic one is transmitted between two clock pulses it shall occur 62.5±15µs after the preceeding clock pulse. If a data bit representing logic zero is to be transmitted there shall be no link integrity test pulses within 125±30µs of the preceeding clock pulse.

The first bit in consecutive FLP Bursts shall occur at a 16±8ms interval (Fig 28-7).

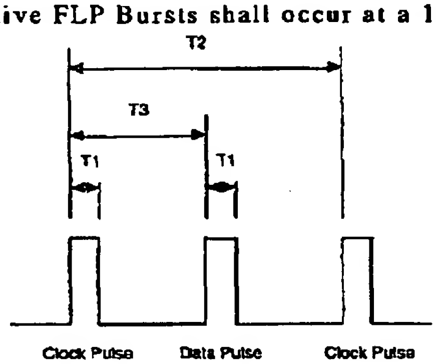


Fig 28-6 FLP Burst pulse to pulse timing

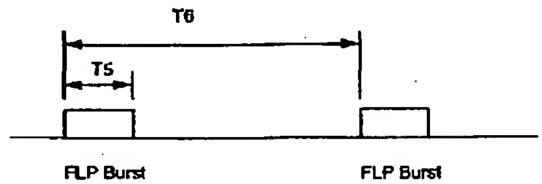


Fig 28-7. FLP Burst burst to burst timing

Table 28-1 FLP Timing Summary

#	Parameter	Min	Typ	Max	units
T1	Clock / Data Pulse Width (Fig 14-12)		100		ns
T2	Clock Pulse to Clock Pulse	95	125	155	µs
T3	Clock Pulse to Data Pulse (Data = 1)	47.5	62.5	77.5	µs
T4	Pulses in a Burst	17		33	#
T5	Burst Width		2		ms
T6	Burst to Burst	8	16	24	ms

28.2.1.1.2 Link Code Word Encoding

The base page transmitted within an FLP Burst shall convey the information shown in Fig 28-8. The NWay Auto-Negotiation function may support additional pages using the Next Page function. In an FLP Burst, D0 shall be the first bit transmitted.

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
NP	RF	A7	A6	A5	A4	A3	A2	A1	A0	Ack	S4	S3	S2	S1	S0

Technology Ability Field (A7–A0) ; Selector Field (S4–S0)

Fig 28-8 Base Page Encoding

28.2.1.1.2.1 Selector Field

Selector Field (S[4:0]) shall be a field five bits wide, encoding 32 possible messages. Selector Field encoding definitions are shown in Annex A. Combinations not specified are reserved for future use. Reserved combinations shall not be transmitted.

28.2.1.1.2.2 Acknowledge

Acknowledge (Ack) is used by the Auto-Negotiation algorithm to indicate that a station has successfully received its link partner's Link Code Word. The Acknowledge Bit shall be encoded in bit D5 regardless of the value of the Selector Field or Link Code Word encoding. If no next page information is to be sent, this bit shall be set to logic one in the Link Code Word, after the reception of at least 3 consecutive and consistent FLP Bursts. If next page information is to be sent, this bit shall be set to logic one only after the station has successfully received at least 3 consecutive and consistent FLP Bursts and saved the current Link Code Word. When the Acknowledge bit is set to logic one the Link Code Word shall be

transmitted 'remaining_ack_cnt_done' times. The value of remaining_ack_cnt_done shall be 6 to 8 inclusive.

28.2.1.1.2.3 Technology Ability Field

Technology Ability Field (A[7:0]) shall be a field 8 bits wide and contain information indicating supported technologies specific to the selector field value. These bits are mapped to individual technologies such that abilities are advertised in parallel for a single selector field value. The technology ability encoding for the IEEE 802.3 selector is described in Annex B-2. Multiple technologies may be advertised in the Link Code Word. A device shall support the data service ability for a technology it advertises within the Link Code Word. It is the responsibility of the priority resolution function to determine the common mode of operation shared by a link partner and to resolve multiple common modes.

NOTE: While devices using a selector field other than the IEEE 802.3 selector field value are free to define the Technology Ability Field bits, it is recommended that the 10BASE-T bit be encoded in the same bit position as in the IEEE 802.3 selector. A common bit position can be important if the technology using the other selector will ever offer a 10BASE-T mode.

28.2.1.1.2.4 Remote Fault

Remote Fault (RF) may be set to logic one to indicate to the Link Partner the presence of a fault. Otherwise, this bit shall be set to logic zero.

28.2.1.1.2.5 Next Page Bit

Next Page (NP) shall be encoded in bit D15 regardless of the value of the Selector Field or Link Code Word encoding. The default value is logic zero. NWay compliant devices shall have the ability to transmit the base Link Code Word as defined in Fig 28-8. Support for transmission and reception of additional Link Code Word encodings is optional. For stations that implement this optional ability, the NP bit in the base Link Code Word shall be set to indicate Next Page ability.. If Next Page ability is not supported, the NP bit shall always be set to logic zero.

While transmitting next pages, setting the NP bit to logic one indicates that there are additional pages to be transmitted after the current page. The NP bit shall be set to logic zero on transmission of the final page.

[Editor's Note: The protocol for negotiation using alternate pages is under discussion.]

28.2.1.2 Receive Function Requirements

The Receive Function shall detect the NLP sequence using the NLP Receive Link Integrity Test Function of Fig 28-16. In addition, the Receive Function shall detect the FLP Burst sequence and decode the information contained within. The FLP/NLP detector shall not detect link pass based on carrier sense. The Receive Function may incorporate a receive switch to control connection to multiple technology dependent link integrity test functions, excluding the 10BASE-T Link Integrity Test Function. If NWay detects link pass from any of the technology dependent link integritytest functions, prior to FLP Burst detection, the nway_wait_timer (28.2.2.2) shall be started. If any other technology dependent link integrity test function indicates LINK_OK when nway_wait_timer expires, NWay shall not allow any

data service to be enabled and shall signal this as a remote fault. The 10BASE-T Link Integrity Test Function shall not be permitted to operate in parallel with NWay's FLP/NLP detector, or with any other technology dependent function.

28.2.1.2.1 FLP Ability Detection and Decoding

In Figs 28-9 to 28-11, the symbol "t_0=0ms" indicates the event which caused the timers described to start and all subsequent times given are referenced from that point. All timers referenced shall expire within the range specifed in Table 28-3.

The Receive Function shall identify the Link Partner as NWay capable if it receives flp_cnt_done consecutive link pulses that are separated by at least flp_test_min_timer time but less than flp_test_max_timer time as shown in Fig 28-9. The value of 'flp_cnt_done' shall be 6 to 17 inclusive. The FLP Burst that identifies the Link Partner as NWay capable shall be ignored for purposes of ability Link Code Word matching. Implementations may ignore multiple FLP Bursts before acknowledging their receipt to allow for potential receive equalization time.

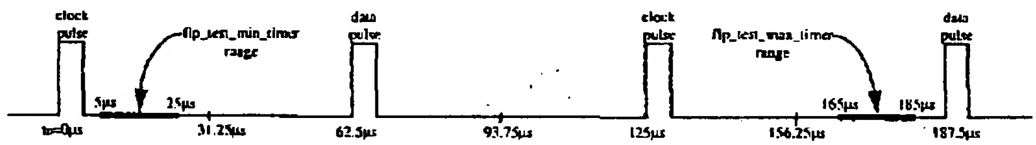


Fig 28-9 FLP Detect Timers (flp_test_min/max_timers)

The Receive Function shall capture and decode link pulses received in FLP Bursts. The first bit in an FLP burst shall be interpreted as a clock link pulse. Detection of a clock link pulse shall restart the data_detect_min_timer and data_detect_max timer. The data_detect_min/max_timers enable the receiver to distinguish data pulses from clock pulses and logic one data from logic zero data, as follows:

> If, during an FLP Burst, a link pulse is recived when the data_detect_min_timer has expired while the data_detect_max_timer h as not expired, the data bit shall be interpreted as a logic one (Fig 28-10).
>
> If, during an FLP Burst, a link pulse is received after the data_detect_max_timer has expired, the data bit shall be interpreted as a logic zero (Fig 28-10) and that link pulse shall be interpreted as a clock link pulse.

As each data bit is identified it shall be stored in the rx_link_code_word. On reception of the Link Code Word, the Receive Function shall ignore the reserved technology ability bits.

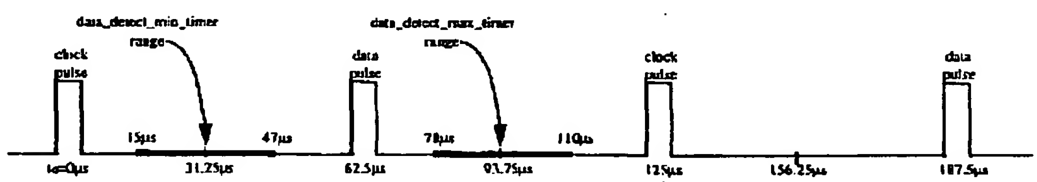


Fig 28-10 FLP Data Detect Timers (data_detect_min/max_timers)

FLP Bursts shall maintain a separation from each other as determined by the nlp_test_min_timer and nlp_test_max_timer as shown in Fig 28-11. The end of a FLP Burst shall be signfied by the expiration of the nlp_test_min_timer after receipt of the final clock or data link pulse in a burst. The FLP Burst separation shall be considered valid if the nlp_test_max_timer has not expired.

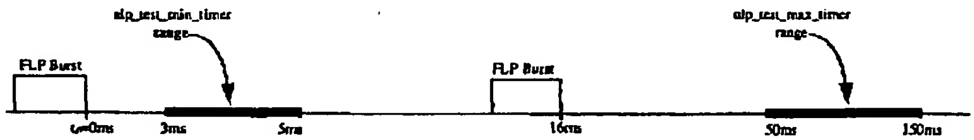


Fig 28-11 FLP Burst Timer (nlp_test_min/max_timers)

28.2.1.2.2 NLP Detection

The NLP detection shall be accomplished via the NLP Receive Link Integrity Test Function in Fig 28-16.

28.2.1.2.3 Receive Switch

The Receive Switch shall enable the receive path from the MDI to one and only one of the technology dependent link integrity test funcitons once negotiation is complete. During negotiation, the Receive Switch may allow more than one technology dependent function to receive signals from the MDI, excluding the 10BASE-T Link Integrity Test Function.

28.2.1.3 Arbitration Function Requirements

The Arbitration Function shall ensure proper sequencing of the NWay Auto-Negotiation algorithm through the Transmit Function and Receive Function. The Arbitration Function shall enable the Transmit Function to advertise and acknowledge abilities. Upon indication of acknowledgement, the Arbitration Function shall determine the highest common denominator using the priority resolution table (Annex B-3) and enable the appropriate technology dependent link integrity test function via the Technology Dependent Interface (28.2.1.5).

28.2.1.3.1 Parallel Detection

NWay shall detect whether the Link Partner supports NWay Auto-Negotiation through reception of FLPs. Prior to detection of FLP Bursts, the Receive Switch may direct MDI receive activity to all technology dependent link integrity test functions, excluding 10BASE-T Link Integrity Test Function. This allows detection of non-NWay Link Partners. If one of the technology dependent link integrity test functions establishes LINK_OK for a specific technology, an nway_wait_timer shall be started. If no other technology dependent link integrity test function indicates LINK_OK when the nway_wait_timer expires, then the selected operational mode shall be the technology which caused the nway_wait_timer to start. If an operational mode is selected, the Arbitration Function shall disable all other link integrity test functions and indicate that NWay Auto-Negotiation has completed.

Parallel Detection shall be supported if 100BASE-TX and/or 100BASE-T4 data services are implemented in an Agile Device. Parallel Detection shall not be implemented for technologies other than 100BASE-TX and 100BASE-T4.

28.2.1.3.2 Renegotiation Function

A renegotiation request from any entity, such as a management agent, shall cause the Arbitration Function to disable all technology dependent link integrity test functions and halt any transmit activity until the technology_[n]_renegotiate_timer expires (28.2.2.2). Consequently, the Link Partner shall go into link fail and negotiation of abilities shall resume. The appropriate tx_link_code_word[16:1] shall be valid prior to the initiation of renegotiation.

28.2.1.3.3 Remote Fault Sensing Function

[Editors Note:The following text is under consideration.

"Remote Fault (RF) can be used by a Local Device to indicate to its Link Partner that a fault condition has occurred. RF is equal to logic one in the event of a fault, and a logic zero otherwise. If the Local Device has no mechanism to detect a fault or associate a fault condition with the Remote Fault indication, then it transmits RF as a logic zero. If the device sets the RF bit, it may also use the NP bit to indicate the Fault Type in the next page it transmits. If RF is set with NP clear, the device is indicating a fault but has no more information on the specific fault type. If the device sets both RF and NP, it shall use the next transmitted page of information to indicate the fault type. An appropriate Annex will be added to indicate Fault Type encoding.

A Local Device that detects a fault and wishes to convey this information to its Link Partner needs to set the RF bit and re-negotiate with the Link Code Word. When the Local Device receives an Acknowledge from the Link Partner, indicating the new Link Code Word has been received, the Local Device resets the RF bit to logic zero."]

28.2.1.4 Management Function Requirements

The management interface is used to communicate Auto-Negotiation information to the management entity. If an MII is physically implemented, then mananagement access is via the MII Management interface. Where no physical embodiment of the MII exists, an equivalent to MII registers 0 ,1,4,5, and 6 are recommended to be provided.

28.2.1.4.1 Media Independent Interface

The basic registers, Control Register (register 0) and Status Register (register 1) provide control and status to and from NWay. The Control Register provides the mechanism to disable, enable, or re-start NWay. The Status Register (register 1) includes information about all modes of operations supported by the Local Station's PHY, the status of Auto-Negotiation, and whether the Auto-Negotiation algorithm is supported by the PHY or not.

The Auto-Negotiation algorithm shall have three dedicated registers:

1) Auto-Negotiation Advertisement Register (register 4)

2) Auto-Negotiation Link-Partner Ability Register (register 5)

3) Auto-Negotiation Expansion Register (register 6)

28.2.1.4.1.1 Auto-Negotiation Advertisement Register (register 4) (R/W)

This register contains the Advertised Ability of the PHY. The bit definition is defined in 28.2.1.1.2. On power-up, before the Auto-Negotiation starts, this register shall have the following configuration:

The Selector Field (4.4:0) is set to an appropriate code as specified in Annex A. The Acknowledge bit (4.5) is set to logic zero. The Technology Ability Field (4.6:13) is set based on the values set in the MII Status Register (register 1) (1.15:11) or equivalent.

Only the bits that represent the technologies supported by the Local Station may be set. Any of the Technology Ability Field bits that may be set can also be cleared by management before a renegotiation. This can be used to enable management to Auto-Negotiate to an alternate common mode.

The management entity may initiate renegotiation with the Link Partner using alternate abilities by setting the Selector Field (4.0:4) and Technology Ability Field (4.6:10) to indicate the preferred mode of operation and setting the Restart Auto-Negotiation bit (0.9) in the Control Register (register 0) to logic one.

28.2.1.4.1.2 Auto-Negotiation Link Partner Ability register (register 5)(RO)

This register contains the Advertised Ability of the Link Partner's PHY. The bit definitions shall be a direct representation of the received Link Code Word (Fig 28-8). Upon successful completion of Auto-Negotiation, Status Register (register 1) Auto-Negotiation Complete bit (1.5) shall be set to logic one.

28.2.1.4.1.3 Auto-Negotiation Expansion register (register 6) (R/W)

The Link Partner NWay Able bit (6.0) shall indicate that the Link Partner is able to participate in the Auto-Negotiation algorithm. The Page Received bit (6.1) shall indicate that 3 identical and consecutive Link Code Wordshave been received. This bit shall be reset on a read of the Auto-Negotiation Expansion register (register 6). Bits 6.15:2 are reserved for future NWay expansion.

[Editor's Note: MII register bits labelled '6.TBD' indicate that the next page protocol is under discussion and bits in register 6 might be allocated for the next page protocol.]

28.2.1.4.1.4 State Diagram Variable to MII register Mapping

The state diagrams of Figs 28-13 to 28-16 generate and accept variables of the form 'mr_x', where x is an individual signal name. These variables comprise a management interface which may be connected to the MII management function or other equivalent function. Table 28-2 describes how the MII registers map to the management function interface signals:

Table 28-2

MII Register	Statc Diagram Variable
4.15:0 Auto-Negotiation Advertisement Register	mr_adv_ability[16:1]
5.15:0 Auto-Negotiation Link Partner Ability Register	mr_lp_adv_ability
6.TBD	mr_lp_np_able
6.0 Link Partner NWay Able	mr_lp_nway_able
6.TBD	mr_np_able
0.12 Auto-Negotiation Enable	mr_nway_enable
1.5 Auto-Negotiation Complete	mr_nway_complete
6.1 Page Received	mr_page_rx
0.9 Auto-Negotiation Restart	mr_restart_negotiation
1.3 Auto-Negotiation Ability	set if NWay is available

In addition, mr_next_page_loaded shall be set when the 4.15:0 Auto-Negotiation Advertisement Register is written.

28.2.1.4.2 Absence of Management Function

In the absence of any management function, the adverised abilities shall be provided through mr_adv_ability[16:1]. If NWay is to be active, mr_nway_enable shall be set to true. If next page is to be supported, a mechanism to process pages beyond the base page before mr_np_able, mr_lp_np_able, or mr_next_page_loaded may be set to true.

28.2.1.4.3 NWay Managed Object Class

The NWay Managed Object Class is defined in Clause 30.

28.2.1.5 Technology Dependent Interface

The Technology Dependent Interface is the interface through which each technology communicates with the NWay sublayer. A PMA shall communicate with NWay through the Technology Dependent Interface. NWay supports multiple technologies, all of which need not be implemented in a given device. Each of these technologies may utilize its own technology dependent link test function.

28.2.1.5.1 PMA_LINK.indicate

This primitive is generated by the PMA to indicate the status of the underlying medium. The purpose of this primitive is to give the PCS, repeater client, or Auto-Negotiation algorithm a means of determining the validity of received code elements.

28.2.1.5.1.1 Semantics of Primitive

PMA_LINK.indicate(link_status)

The link_status parameter shall assume one of three values: LINK_IN_PROGRESS, LINK_OK or LINK_FAIL, indicating whether the underlying medium is attempting to synchronize (LINK_IN_PROGRESS), intact (LINK_OK), or not available (LINK_FAIL). When link_status=LINK_FAIL or link_status=LINK_IN_PROGRESS the PMA_CARRIER.indicate and PMA_UNITDATA.indicate primitives are undefined.

28.2.1.5.1.2 When Generated

The PMA shall generate this primitive to indicate the value of link_status.

28.2.1.5.1.3 Effect of Receipt

The effect of receipt of this primitive shall be governed by the state diagrams of Figs 28-13 to 28-15.

28.2.1.5.2 PMA_LINK.request

This primitive shall be generated by the Auto-Negotiation algorithm. The purpose of this primitive is to allow the Auto-Negotiation algorithm to enable and disable operation of the PMA.

28.2.1.5.2.1 Semantics of Primitive

PMA_LINK.request(link_control)

The link_control parameter can take on one of three values: SCAN_FOR_CARRIER, DISABLE, or ENABLE.

The link_control=SCAN_FOR_CARRIER mode is used by the Auto-Negotiation algorithm prior to receiving any FLPs or LINK_OK indications. During this mode the PMA shall search for carrier and report link_status=OK when carrier is received, but no other actions are enabled.

The link_control=DISABLE mode is used by the Auto-Negotiation algorithm to disable PMA processing in the event of FLP detection or LINK_OK indications. This gives the Auto-Negotiation algorithm a chance to determine how to configure the link.

The link_control=ENABLE mode is used by Auto-Negotiation to turn control over to the PMA for all normal processing functions.

28.2.1.5.2.2 Default Value of Parameter link_control

Upon power-on, reset, or release from power-down the link_control parameter shall revert to the LINK_ENABLE state. If the optional Auto-Negotiation algorithm is not implemented no PMA_LINK.request message will arrive and the PMA will operate indefinitely in the ENABLE state.

28.2.1.5.2.3 When Generated

The Auto-Negotiation algorithm shall generate this primitive to indicate to the PHY how to respond.

Upon power-on or reset the Auto-Negotiation algorithm shall issue the message PMA_LINK.request(SCAN_FOR_CARRIER).

28.2.1.5.2.4 Effect of Receipt

The effect of receipt of this primitive shall be governed by the receiving technology dependent link integrity test function, based on the intent specified in the primitive semantics.

28.2.2 State Diagrams

The notation used in the state diagrams (Figs 28-13 to 28-15) follows the conventions in 1.2.1. The variables, timers, and counters used in the state diagrams are defined in the following sections, 14.2.3, and 28.2.1.5.

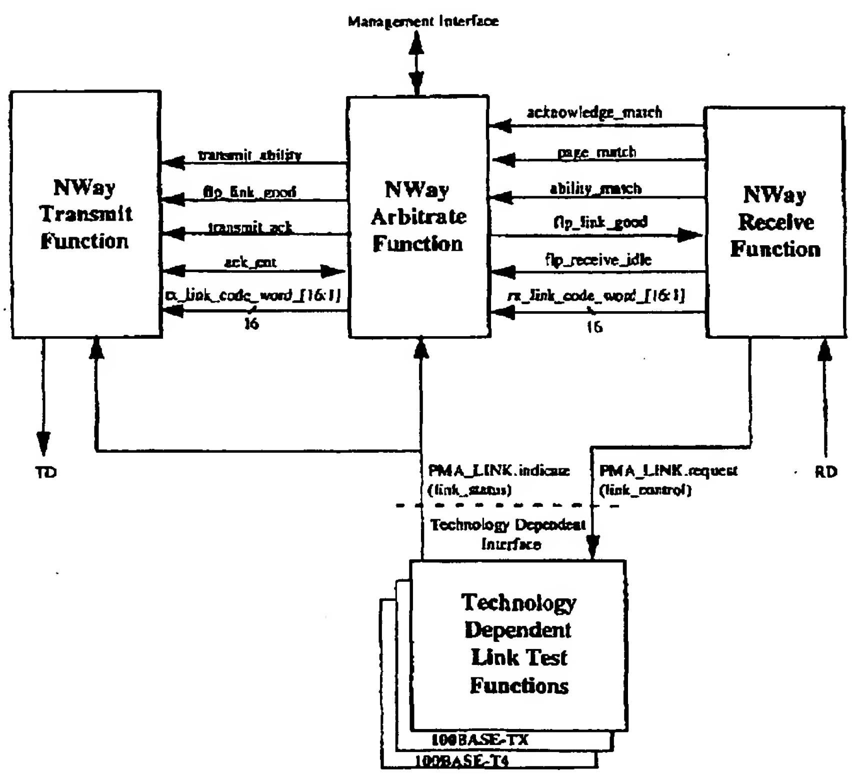


Fig 28-12 Functional Reference Diagram

28.2.2.1 State Diagram Variables

Variables with '_[x]' appended to the end of the variable name indicates a variable or set of variables as defined by 'x'. 'x' may be:

n; represents any one of the specific technologies supported by the Local Station.
all; represents all specific technology dependent link test functions suppo rted in the Local Station.
HCD; represents the single technology dependent link test function chosen by NWay as the highest common denominator technology.
notHCD; represents all technology dependent link test functions not chosen by NWay as the highest common denominator technology.

Variables with [16:1] appended to the end of the variable name indicate arrays which can be directly mapped to 16 bit registers. For these varibles, '[x]' indexes an element or set of elements in the array, where '[x]' may be:

any integer
any variable which takes on integer values
NP; represents the index of the Next Page bit
ACK; represents the index of the Acknowledge bit.
RF; represents the index of the Remote Fault bit

Variables of the form 'mr_x', where x is a label, comprise a management interface which is intended to be connected to the MII Management function. However, an implementation specific management interface may provide the control and status function of these bits.

ability_match. Indicates that 3 consecutive Link Code Words match, ignoring the Acknowledge bit.
Values: false; 3 matching consecutive Link Code Words have not been received, ignoring the Acknowledge bit (default).
true; 3 matching consecutive Link Code Words have been received, ignoring the Acknowledge bit.

base_page. Status indicating that the page currently being transmitted by NWay is the initial Link Code Word encoding used to communicate the node's abilities.
Values: false; a page other than base Link Code Word is being transmitted.
true; the base Link Code Word is being transmitted.

acknowledge_match. indicates that 3 consecutive Link Code Words have the Acknowledge bit set.
Values: false; 3 consecutive Link Code Words have not been received with the Acknowledge bit set (default).
true; 3 consecutive Link Code Words have been received with the Acknowledge bit set.

flp_link_good. Indicates that the NWay negotiation has completed.
Values: false; negotiation is in progress (default).
true; negotiation is complete, forcing the Transmit Function to IDLE.

flp_receive_idle. Indicates that the FLP Receive state diagram is in the Idle state.
Values: false; the FLP receive state machine is not in the Idle state (default).
true; the FLP receive state machine is in the Idle state.

linkpulse. Indicates that a valid Link Pulse as defined in Fig 14-12 has been received.
Values: false; linkpulse is set to false after any Receive State Diagram state transition (default).
true; linkpulse is set to true when a valid Link Pulse is received .

mr_adv_ability[16:1]. A 16 bit array that contains the Advertised Abilities Link Code Word.
For each element within the array:
Values: Zero; Data bit is logical zero.
One; Data bit is logical one.

mr_lp_adv_ability[16:1]. A 16 bit array that contains the Link Partner's Advertised Abilities Link Code Word.
For each element within the array:
Values: Zero; Data bit is logical zero.
One; Data bit is logical one.

mr_lp_np_able. Status indicating whether the Link Partner supports next page exchange.
Values: false; the Link Partner does not support next page exchange.
true; the Link Partner supports next page exchange.

mr_np_able. Status indicating whether the Local Station supports next page exchange.
Values: false; the Local Station does not support next page exchange.
true; the Local Station supports next page exchange.

mr_lp_nway_able. Status indicating whether the Link Partner supports NWay Auto-Negotiation
Values: false; the Link Partner does not support NWay Auto-Negotiation.
true; the Lnk Partner supports NWay Auto-Negotiation.

mr_page_rx. Status indicating whether a new page has been received.
Values: false; a new page has not been received.
true; a new page has been received.

mr_next_page_loaded. Status indicating whether a new page has been loaded into mr_adv_ability.
Values: false; a new page has not been loaded.
true; a new page has been loaded.

mr_nway_enable. Controls the enabling and disabling of the NWay Auto-Negotiation function.
Values: false; NWay Auto-Negotiation is disabled.
true; NWay Auto-Negotiation is enabled.

mr_nway_complete. Status indicating whether the NWay Auto-Negotiation has completed.
Values: false; NWay Auto-Negotiation has not completed.
true; NWay Auto-Negotiation has completed.

page_match. Indicates that 3 identical and consecutive Link Code Words have been received with the Acknowledge bit cleared.
Values: false; 3 identical and consecutive Link Code Words have not been received with the Acknowledge bit cleared.
true; 3 identical and consecutive Link Code Words have been received with the Acknowledge bit cleared.

renegotiate. Forces restart of the Auto-Negotiation algorithm.
Values: false; no renegotiation required (default).
true; re-start Auto-Negotiation algorithm.

rx_link_code_word[16:1]. A 16 bit array which contains the data bits to be received from an FLP Burst.
For each element within the array:
Values: zero; Data bit is a logical zero
one; Data bit is a logical one

transmit_ability. Controls the transmission of the Link Code Word containing the Local Station's Advertised Ability. The state of the Acknowledge bit in the Link Code Word is controlled by the transmit_ack state variable.
Values: false; any transmission of the Advertised Ability is halted (default).
true; the transmit state diagram begins sending the Advertised Ability.

transmit_ack. Controls the setting of the Acknowledge bit in the Link Code Word to be transmitted.
Values: false; allows the Acknowledge bit to be set to a logic zero (default).
true; allows the Acknowledge bit to be set to a logic one.

tx_link_code_word[16:1]. A 16 bit array which contains the data bits to be transmitted in an FLP Burst. This array may be loaded from multiple sources. The initial loading shall be from the base Link Code Word state variable.
For each element within the array:
Values: Zero; Data bit is logical zero.
One; Data bit is logical one.

28.2.2.2 State Diagram Timers

All timers operate in the manner described in 14.2.3.2.

data_detect_min_timer. Timer for the minimum time between a clock pulse and the next link pulse. This timer is used to detect whether the data bit between two clock pulses is a logic zero or a logic one. The data_detect_min_timer shall expire between 15 -47 µs from the last clock pulse.

data_detect_max_timer. Timer for the maximum time between a clock pulse the next link pulse. This timer is used to detect whether the data bit between two clock pulses is a logic zero or a logic one. The data_detect_max_timer shall expire between 78 -110 µs from the last clock pulse.

flp_test_min_timer. Timer for the minimum time between two link pulses within an FLP Burst. This timer is used to detect whether the Link Partner is transmitting FLP Bursts. The flp_test_min_timer shall expire between 5-25 µs from the last link pulse.

flp_test_max_timer. Timer for the maximum time between two link pulses within an FLP Burst. This timer is used to detect whether the Link Partner is transmitting FLP Bursts. The flp_test_max_timer shall expire between 165-185 µs from the last link pulse.

interval_timer. Timer for the separation of a transmitted clock pulse from a data bit. The interval_timer shall expire 62.5±15µs from each clock pulse and data bit.

nlp_test_min_timer. Timer for the minimum time between two consecutive FLP Bursts. The nlp_test_min_timer shall expire between 3-5 ms from the last pulse in an FLP Burst.

nlp_test_max_timer. Timer for the maximum time between two consecutive FLP Bursts. The nlp_test_min_timer shall expire between 50-150 ms from the last pulse in an FLP Burst.

nway_wait_timer. Timer for the amount of time to wait before evaluating the number of link integrity test functions with LINK_OK asserted. The nway_wait_timer shall expire TBD.

technology_[n]_renegotiate_timer. Timer that specifies the amount of time to wait before beginning transmission of FLPs after renegotiate is asserted. This time shall be the longest period of time it takes to bring the link down for all supported technologies.

transmit_link_burst_timer. Timer for the separation of a transmitted FLP Burst from the next FLP Burst. The transmit_link_burst_timer shall expire 6-22 ms after the last transmitted link pulse in an FLP Burst.

Table 28-3: Timer Min/Max Value Summary

Parameter	Min	Typ	Max	units
data_detect_min_timer	15		47	µs
data_detect_max_timer	78		110	µs
flp_test_min_timer	5		25	µs
flp_test_max_timer	165		185	ms
interval_timer	47.5	62.5	77.5	µs
nlp_test_min_timer	3		5	ms
nlp_test_max_timer	50		150	ms
nway_wait_timer	TBD		TBD	
transmit_link_burst_timer	6	14	22	ms

28.2.2.3 State Diagram Counters

remaining_ack_cnt. A counter which may take on integer values from 0 to 8. The number of additional Link Code Words with the Acknowledge Bit set to logic one to be sent to ensure that the Link Partner receives the acknowledgement.

Values: remaining_ack_cnt_not_done; positive integers between 0 and 5 inclusive.
remaining_ack_cnt_done; positive integers 6 to 8 inclusive (default).
init; counter is reset to zero.

rx_bit_cnt. A counter which may take on integer values from 0 to 16. This counter is used to keep a count of data bits received from an FLP Burst. When this variable reaches 16, all data bits have been sent

Values: rx_bit_cnt_not_done; 1 to 15 inclusive.
rx_bit_cnt_done; 16.
init; counter is reset to zero.

tx_bit_cnt. A counter which may take on integer values from 1 to 17. This counter is used to keep a count of data bits sent within an FLP Burst. When this variable reaches 17, all data bits have been sent

Values: tx_bit_cnt_not_done; 1 to 16 inclusive.
tx_bit_cnt_done; 17.
init; counter is initialized to 1.

flp_cnt. A counter which may take on integer values from 0 to 17. This counter is used to keep a count of the number of FLPs detected to enable the determination of whether the Link Partner supports NWay.

Values: flp_cnt_done; 6 to 17 inclusive.
flp_cnt_not_done; 0 to 5 inclusive.
init; counter is reset to zero.

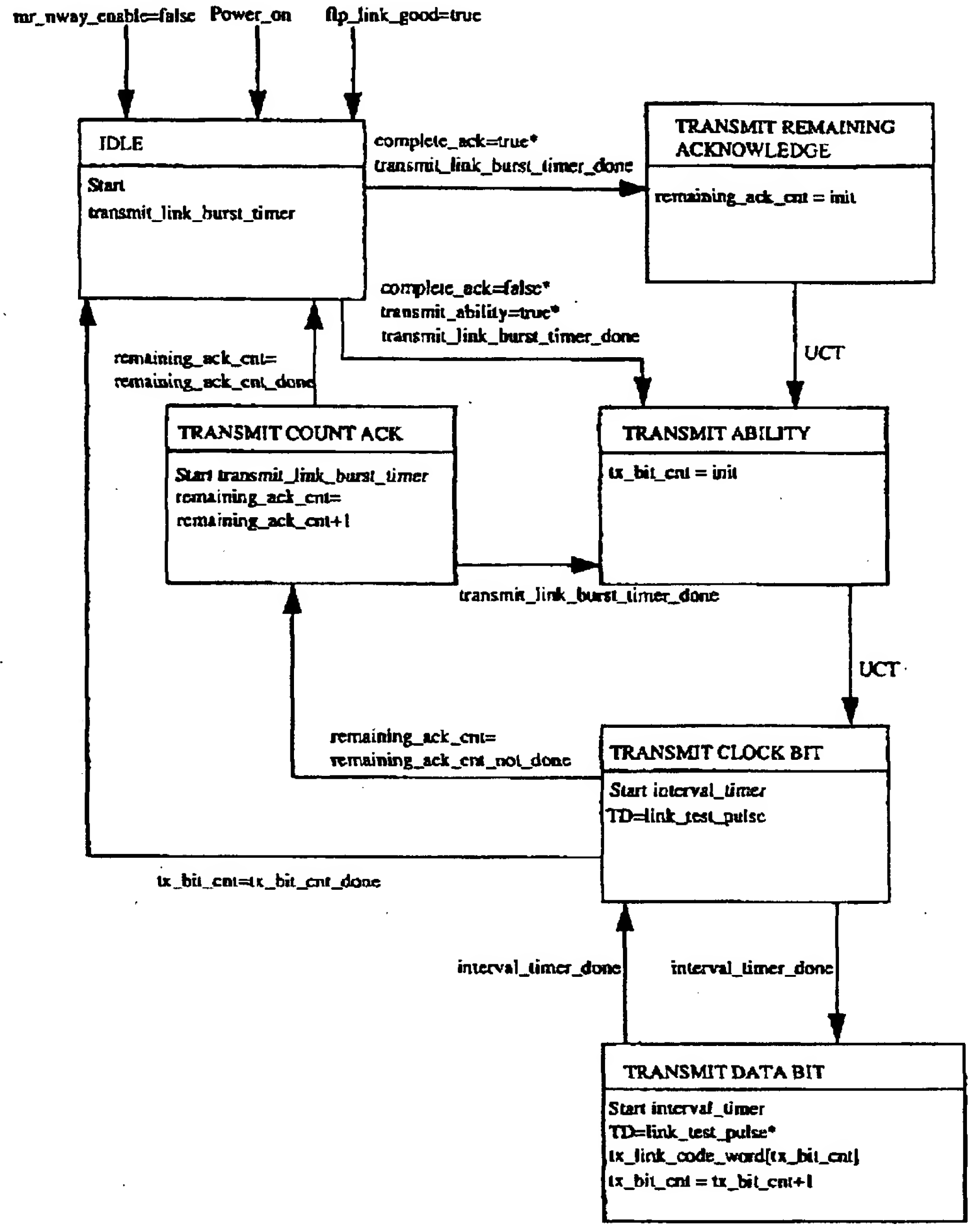
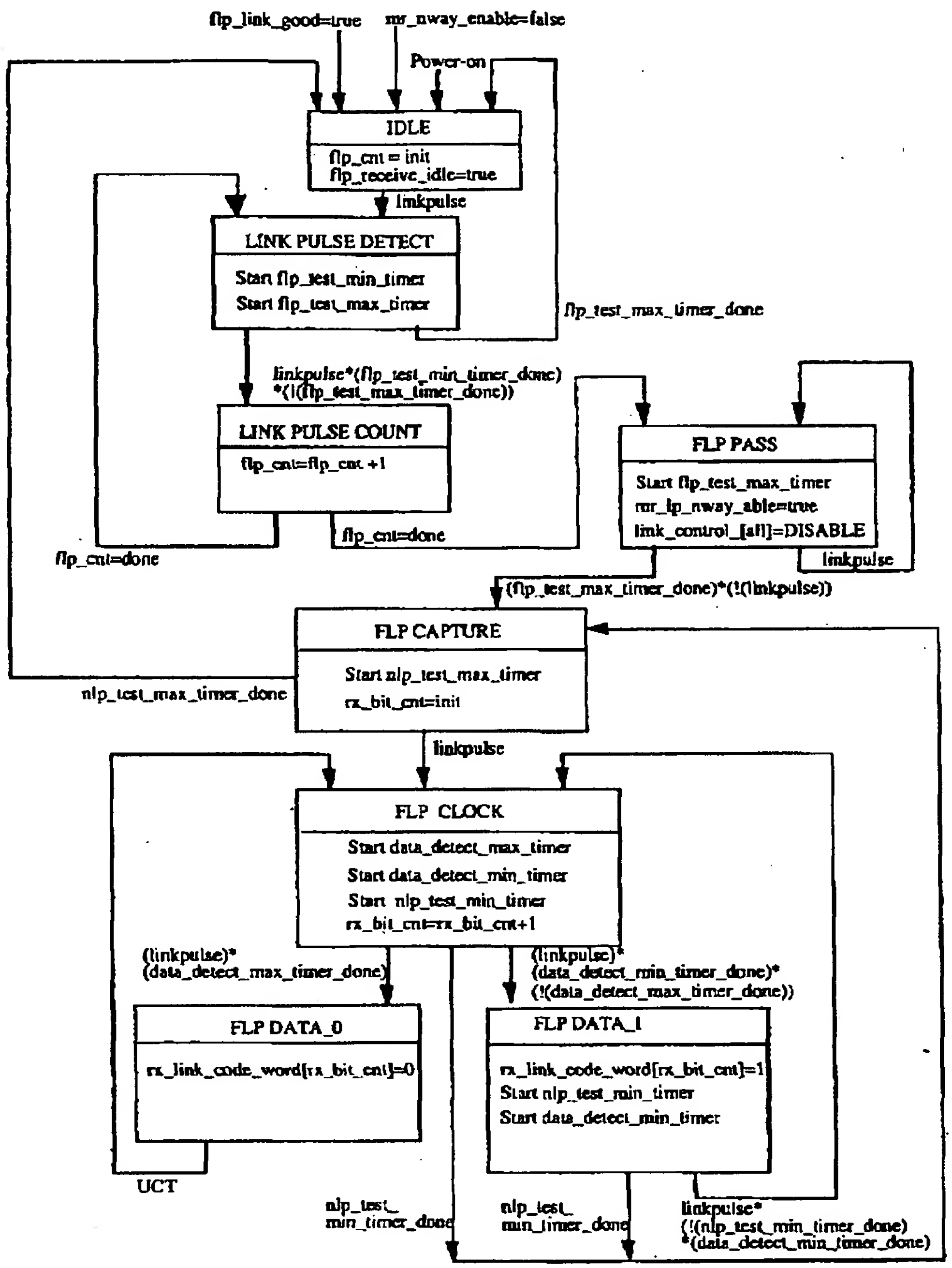


Fig 28-13 Transmit State Diagram



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2 **Figure 28-14 Receive State Diagram**

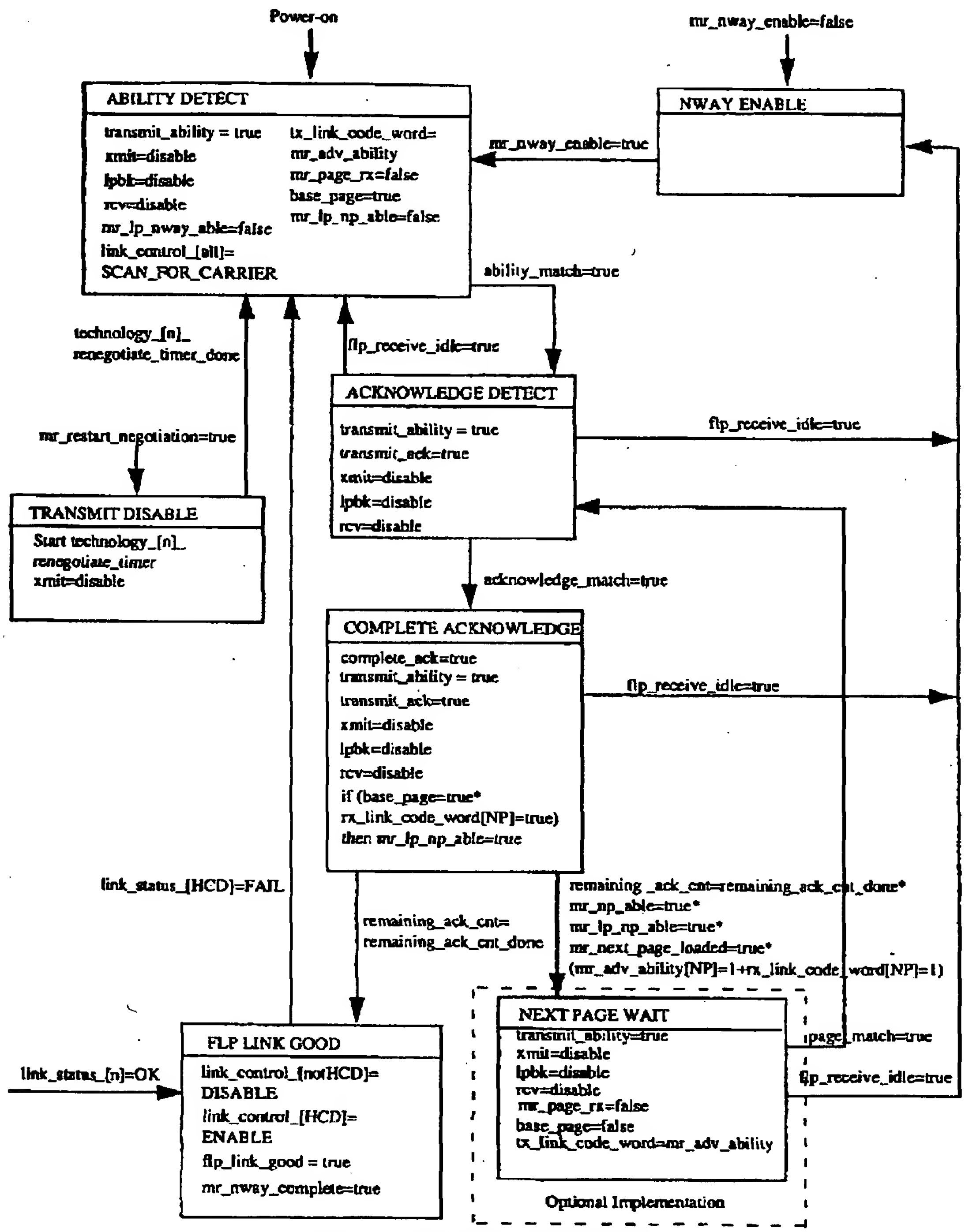

Fig 28-15 Arbitration State Diagram

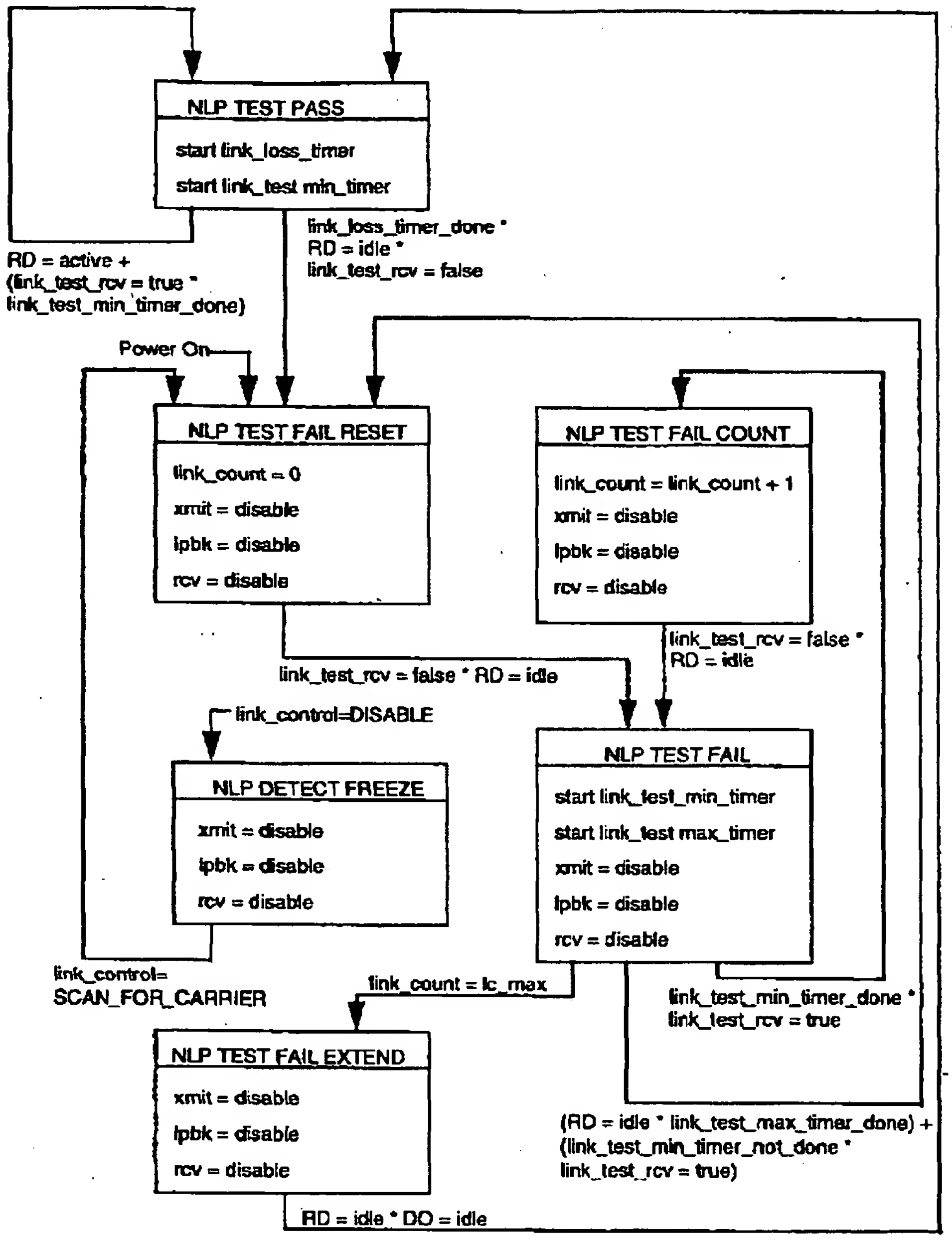

Fig 28-16 NLP ReceiveLink Integrity Test Function State Diagram

28.3 Electrical Specifications

The electrical characteristics of pulses within FLP Bursts shall be identical to the characteristics of NLPs and shall meet the requirements of Fig 14-12. FLPs are transmitted single ended on the positive wire of the transmit pair.

NWay is a completely passive electrical interface . No signal amplitude or attenuation is assumed present. It shall be the responsibility of the technology specific transmit and receive functions to interface to the MDI correctly.

ANNEX Overview

NWay is designed in a way that allows it to be easily expanded as new technologies are developed. When a new technology is developed, three things must be done to allow NWay to support it.

1. The appropriate Selector Field value to contain the new technology must be selected and allocated.

2. A Technology bit must be allocated for the new technology within the chosen Selector Field value.

3. The new technology's relative priority within the technologies supported within a Selector Field value must be established.

4. The Technology Dependent Timers must be updated to reflect the new technology's requirements.

Additions and insertions to the Annexes are allowed. No changes to existing bits already defined shall be allowed.

ANNEX 28A (Normative)

28.A1 Selector Field Definitions

The Selector Field, S[4:0] in the Link Code Word, shall be used to identify the type of message being sent by NWay. The following table identifies the types of messages that may be sent. As new messages are developed, this table will be updated accordingly.

The Message Selector field uses a 5 bit binary encoding which allows 32 messages to be defined. All unspecified combinations are reserved. Reserved combinations shall not be transmitted.

Table A1. FLP Selector Field Values

S4	S3	S2	S1	S0	Selector Description
0	0	0	0	0	RESERVED for Future NWay Development
0	0	0	0	1	IEEE 802.3
1	1	1	1	1	RESERVED for Future NWay Development

ANNEX 28B: IEEE 802.3 Selector Base Page Definition (Normative)

This section provides the Technology Ability Field bit assignments, Priority Resolution table, and Technology Dependent Timer values relative to the IEEE 802.3 Selector Field valuewithin the base page encoding.

As new IEEE 802.3 LAN technologies enter the market a reserved bit in the Technology Ability Field may be assigned to each technology by the standards body.

The new technology shall then be inserted into the Priority Resolution table and made a part of the Auto-Negotiation standard. The relative hierarchy of the existing technologies will not change, thus providing

backward compatibility with existing NWay implementations. The Technology Dependent timers shall be updated to account for the needs of the new technology.

It is important to note that the reserved bits are forced to zeros. This guarantees that devices implemented using the current priority table will be forward compatible with future devices using an updated priority table.

28.B1 Selector Field Value

The value of the 802.3 Selector Field is S[4:0] = 00001.

28.B2 Technology Ability Field Bit Assignments

The Technology bit field consists of bits D6 through D13, (A0-A8 respectively) in the IEEE 802.3 Selector Base Page. Table B1 summarizes the bit assignments.

Note that the order of the bits within the Technology Bit Field has no relationship to the relative priority of the technolgies.

Table B1: FLP Technology Ability Field Bit Assignments

Bit	Technology
A0	10BASE-T
A1	10BASE-T Full Duplex
A2	100BASE-TX
A3	100BASE-TX Full Duplex
A4	100BASE-T4
A5	Reserved for future technologies
A6	Reserved for future technologies
A7	Reserved for future technologies

28.B3 Priority Resolution Table

Since two nodes can have multiple abilities in common a prioritization scheme shall exist to ensure that the highest common denominator ability is chosen. The following list shall represent the relative priorities of the technologies supported by the 802.3 Selector Field value, where priorities are listed from highest to lowest.

1. 100BASE-TX Full Duplex
2. 100BASE-T4
3. 100BASE-TX
4. 10BASE-T Full Duplex
5. 10BASE-T

The rational for this hierarchy is straightforward. 10BASE-T is the lowest common denominator and therefore has the lowest priority. Full Duplex solutions are always higher in priority than their Half Duplex counterparts. 100BASE-T4 is ahead of 100BASE-TX because 100BASE-T4 runs across a broader spectrum of copper cabling. The relative order of the technologies specified herein shall not be changed. As each new technolgy is added, it shall be inserted into its appropriate place in the list, shifting technologies of lesser priority lower in priority.

28.B4 Technology Dependent Timers

28.B4.1 Link_Fail_Inhibit_Timer

The link_fail_inhibit_timer is used to qualify a LINK_FAIL indication to a LINK_IN_PROGRESS indication when a specific technology link is first being established. A link will only be considered 'failed' if the link_fail_inhibit_timer has expired and the link has still not gone into the LINK_OK state.

The link_fail_inhibit_timer is composed of 2 timing requirements. The first timing requirement is that both sides of a link have finished NWay Auto-Negotiation. The maximum time difference between a Local Station and its Link Partner completing NWay Auto-Negotiation is:

(Maximum FLP Burst to Burst separation) x (Maximum # of FLP Bursts needed to complete acknowledgement with 1 bit error, with worst case placement) = (24ms) x (6 bursts) = 144 ms.

The second timing requirement is the technology specific time required to bring up a link. The following table gives the technology specific times required to bring up a link plus the time required to complete NWay Auto-Negotiation. This is the time that the link_fail inhibit_timer should expire when attempting to bring up a specific technology.

Table B2: Technology Specfic Link_Fail_Inhibit_Timer values

Technology	Min	Max	units
10BASE-T			
100BASE-TX			
100BASE-T4	504	1000	ms